Environmental analysis of residential building facades through energy consumption, GHG emissions and costs.

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Summary

This paper provides some results on the potential to minimize environmental impacts in residential buildings life cycle, through façade design strategies, analyzing also their impact on costs from a lifecycle perspective. On one hand, it assesses the environmental damage produced by the materials of the building envelope, and on the other, the benefits they offer in terms of habitability and liveability in the use phase. The analysis includes several design parameters used both for rehabilitation of existing facades, as for new facades, trying to cover various determinants and proposing project alternatives. With this study we intended to contribute to address the energy challenges for the coming years, trying also to propose pathways for innovative solutions for the building envelope.

Keywords: building envelope, facade, energy consumption, green house gas emissions, cost benefit, life cycle.

1. Introduction

Studies relating energy and green house gas emissions in the construction sector have been gaining popularity in recent years due to the important mitigation potential of the GHG emissions on this sector. [1]. According to Eurostat, in Europe in 2008, the final energy consumption in the household sector meant a 27% from the overall energy consumption [2] In Spain, the EECCEL [3] has some urgent actions for buildings, establishing two indicators for housing: the CO2 emissions from each dwelling and the total final energy consumption in dwellings (air conditioning, heating, hot water, appliances and cooking). This same document indicates as relevant the fact that the “Non metallic minerals” industrial sector (cement, glass, and ceramic) means more than the 21% of the total energy consumptions of the industry in Spain. On the other hand, in Spain, 39% of the dwellings have double glazing, 11.4% have window frames with thermal bridge break, 70,3% have heating systems and 35,5% cooling systems, with a geographical distribution related with the different climates of the country[4].

There are multiple tools, studies and publications related to the amount of energy used in the building operation, and there are also many recent studies which focus on the “cost-benefit” energy efficiency strategies in building construction, in which the investment is considered in economical terms, and the benefit in environmental terms. [5] [6] [7] [8] [9]. Nevertheless, the relation of environmental impact in the different phases of the life cycle of the building has been studied in less occasions, both through life cycle inventory and analysis, and through simplified methods, and generally applied to specific case studies or to specific construction elements. [10] [11] [12] [13] [14] [15] [16]. These studies offer us a point of view which allows to put in relation the impact associated to the different materials, with the impact produced in the use phase of the buildings, that enables to analyse the environmental feasibility of the different constructive strategies as a starting point for the study of the economical feasibility.

This paper aims to analyze and give a point of view of the different improvement potential of the facade building components focusing on the costs-benefit relation in environmental terms. In this way, it analyzes the environmental benefits that will be produced during the use of the dwelling in terms of energy consumption and GHG emissions, and its relation with the energetic investment associated to the materials used for its construction. This paper completes other results what were presented by the same authors in SB10fi through a focus on materials.

2. Methodology and scope

The goal of the methodology is to obtain several data to correlate the consumption in the use phase, in this case thermal performance of buildings (heating and cooling) with the consumption of materials. For this purpose, the LEADER program [17] was used to calculate energy demand in the use stage, as it calculates building demand under the standard conditions required for residential buildings energy certification in Spain, and BEDEC database [18] to estimate the environmental impact and costs for different materials. To compare the data associated with the materials with thermal performance, the units are given per net floor square meter, considering half of the floor area for each facade, and per year, assuming a 50 year average life span for materials.

To limit the facade study to the scale of a building component, a typical geometry was considered: that of a dual-aspect flat, in which both horizontal surfaces and two of the vertical ones would be in contact with spaces with identical use conditions. Its net floor area is 78,7m2 (the area of an average flat in Spain [19], its volume is 208,69m3 and the facade area in contact with the exterior is 39,75 m2. To study energy demand, certain fixed parameters were established, and the changes caused by a series of variables were analysed. These variables are:

Location: Twelve provincial capitals were chosen to represent the different climate zones in Spain, according to the combinations of winter (SCI) and summer (SCV) climate severity [20].

Orientation: The following orientations were used: 0º, 90º, 135º, 180º, 225º, 270º.

Sun exposure: In analysing the different cases, data on the solar collection that takes place through the glazed openings was also used. Two further variables were added to the study: with and without solar collection.

Ventilation: The room air change rate per hour was also included as a study variable, with 1,0 h^{-1}, 0,6 h^{-1}, and 0,2 h^{-1}.

Facade composition: To limit the number of cases, the following facade treatments were used, differentiating between the blind part (wall) and the openings (window):

-Wall type: There are nine different wall compositions, depending on thermal transmittance U, and mass. Three U values were used: U=0,3 W/m²K, U=0,6 W/m²K and U=0,9 W/m²K, each of them with three different compositions, all with the insulating material on the outside. Three mass composition were selected for each U value, the main difference between them is the amount of mass inside the exterior wall: M1, insulation+mass, which corresponds to the most conventional facade, bearing in mind current building practice in Spain; M2, primarily comprising insulating material, representing a lightweight, insulating wall; and M3, with greater mass inside the wall, and therefore higher inertia.

-Opening type: Two types of opening were used: H1, in which the thermal transmittance values of the glass and the frame are 1,6 W/m²K and 3,2 W/m²K, respectively (1,76 W/m²K average

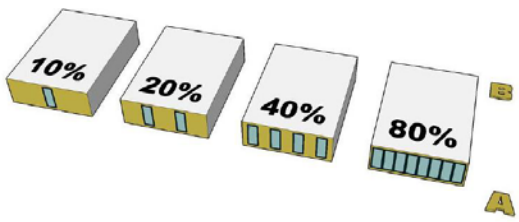

Fig. 1 Opening/wall percentage in facades for the studied geometry

transmittance), and H2 with 3,3 W/m²K for the glass and 5,7 W/m²K for the frame (3,54 W/m²K average transmittance). The percentage of the opening covered by the frame was considered to be 10 % in all cases.

-Opening/wall percentage: The size of the openings acts independently as a variable in both facades. Four cases were selected with openings representing 10 %, 20 %, 40 % and 80 % of each facade, resulting in combinations where openings cover 10 %, 15 %, 20 %, 25 %, 30 %, 40 %, 45 %, 50 %, 60 % and 80 % of the surface of the two facades.
To calculate the embodied energy according to the percentage of openings in the façade, it has been considered a linear relationship, ie twice the area of opening, is twice embodied energy.

The variables on which the materials have an influence in terms of environmental investment, are the composition of the facade (type of opening and wall), and the proportion of openings. Thus, the benefits obtained by, for example an optimal orientation, are considered "free" in terms of environmental investment. The location or climate zone is not a variable that has been taken into account in the impact of materials, taking out of this study criteria such as the use of local materials, but nevertheless, it has been considered for the use phase due to differences in thermal performance by climate zone.

It may be recalled here that although other environmental impacts and other phases that are considered in a life cycle analysis for the components, in this case have fallen outside the scope of study, they may have an important impact when evaluating facade composition.

3. Results

To display all the data collected, we are currently developing a tool for designers as the combination of parameters has led to 124.416 results. Fig 2. shows an example of the variations in energy demand for heating and cooling in the cases studied for three of the twelve different locations. The first graph at the top corresponds to Almería, with less dispersion, and less mean energy demand (mainly for cooling). Madrid, with both heating and cooling demand, becomes more disperse, and Leon, shows higher mean and dispersion than the previous two, due to more severe winter weather conditions.
The analysis of results will be focused on those parameters affecting materials environmental impacts, represented just for the cases located in Madrid.

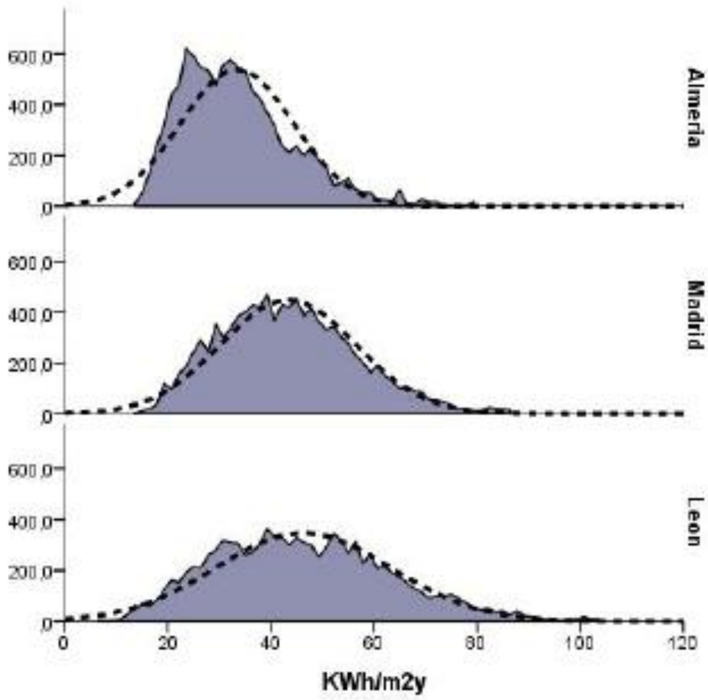

Fig. 2 Frecuency of energy demand (KWh/m^2y) for different climate zones (Almería, Madrid y León)

3.1 Materials / use:

To relate the environmental impacts and costs of materials with the thermal performance, we consider several issues, including:

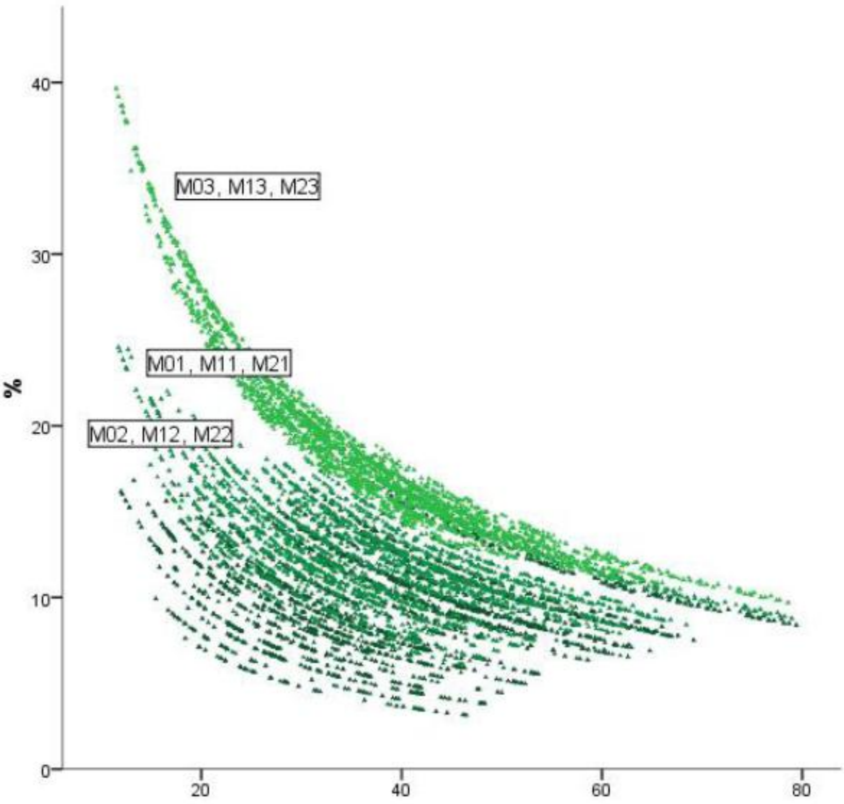

Fig. 3 Percentage of embodied energy in facade materials related to energy demand for heating and cooling (Madrid)

-More moderate climate zones, have lower operation impacts and costs, so materials will have higher relative impacts.
-Differences in heating and cooling demand for each climatic zone, implies diferent types of systems and facilities, with its implications in CO2eq emissions and costs.
-Component service life can vary considerably, not necessarily in response to technical reasons, representing an increase or decrease on the annual materials impact.
- In the case of new construction, façade components have undergone several transformations before reaching into use, as reflected in the energy CO2eq and cost incorporated. In the case of rehabilitation of existing buildings, this components are already under use conditions. The changes to improve their skills, such as the addition, replacement or repair of components also creates a material investment, wich amount will depend on the ability to reuse existing components.

Fig. 3 shows how for the type of walls and openings detailed in tab.1, the variations in energy demand are important, leading to also important changes in the impact of materials. As this demand is reduced, the percentage of energy that corresponds to the material increases. It is also observed how for the same opening-wall combination, represented by the different lines, different demands can be reached, depending on how the remaining variables are distributed. In the cases here studied, the walls with greater amount of mass correspond with the ones of highest embodied energy, and although openings have very different features, they have similar embodied energy and emissions. With other building systems, such as earth walls or wood window frames with similar features, these environmental impacts would be reduced. In the case of enviromental retrofit of buildings, the existing layer is set outside from the accounting of energy consumption of materials, which already by itself makes a significant impact reduction.

	U (W/m²K)	Mass	KWh/m²	CO2eq/m²	€/m²
M01	0,3	1	320,82	129,18	111,59
M02	0,3	0	154,79	82,36	53,17
M03	0,3	2	731,05	248,86	297,96
M11	0,6	1	254,28	93,82	96,725
M12	0,6	0	88,24	47	37,15
M13	0,6	2	664,51	213,5	283,095
M21	0,9	1	232,54	82,265	94,45
M22	0,9	0	67,77	36,12	32,875
M23	0,9	2	642,77	201,945	280,82
H1	1,76	-	894,67	420,59	257,17
H2	3,54	-	885,18	416,04	178,92

Table 1. Wall and window characteristics (per facade square meter).

3.2 Type of wall/thermal mass

As there are three different compositions with the same thermal transmittance for each U value, the primary difference lies in the distribution of the wall mass toward the interior, which provides some information about the influence of the thermal inertia of this mass. Thermal mass has a significant effect on cooling loads, but not on heating loads. For cooling, the load varies throughout the day, while heating loads vary over the course of a year. In any case, this mass has a positive effect on energy demand, and even more so when combined with other parameters, such as sun exposure and ventilation, as shown in fig.4. Reducing thermal transmittance has a positive effect on heating loads.

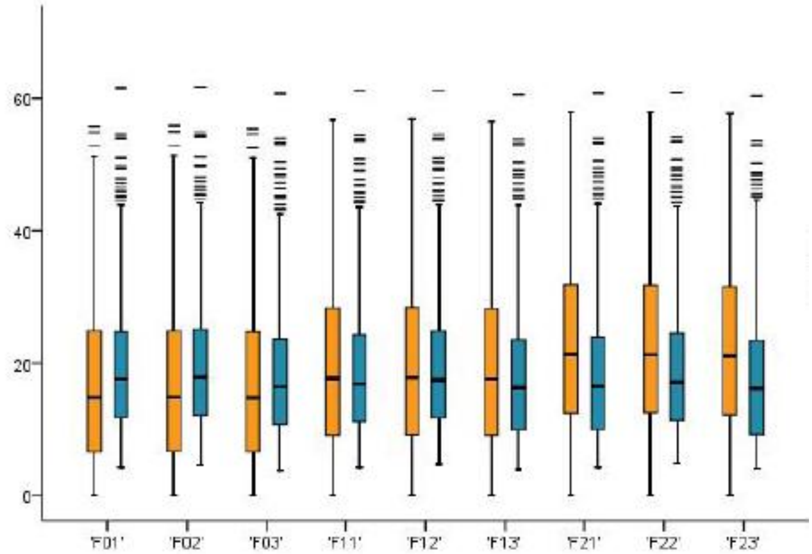

Fig. 4 Heating and cooling demand (KWhm2y) for different wall types for Madrid

3.3 Opening type

Façade openings are one of the most complex elements in terms of energy analysis, since it combines several parameters into a single design element. For example, the thermal performance of glass and frame will determine the transmission losses, and the type of glass, its orientation or setback play an important role in solar gains. Other parameters such as air leakage are defined by the type of frame. In this case we have studied two different types of openings, which are those that provide the data for heating and cooling demand. This parameter is one of those with the greatest influence on heating demand, but it is tremendously influenced by other parameters such as orientation or solar access.

3.4 Opening/wall percentage

An increase in the percentage of openings generally means an increase in both heating and cooling demand. The main difference between these two types of facade elements (openings and wall) is their potential for solar gain and transmittance. The percentage of openings is closely linked to orientation (the potential for solar gain is greater if this percentage is higher) and composition (the larger the percentage, the more transmittance losses, as the blind part of both types of opening provides more insulation in the cases studied).

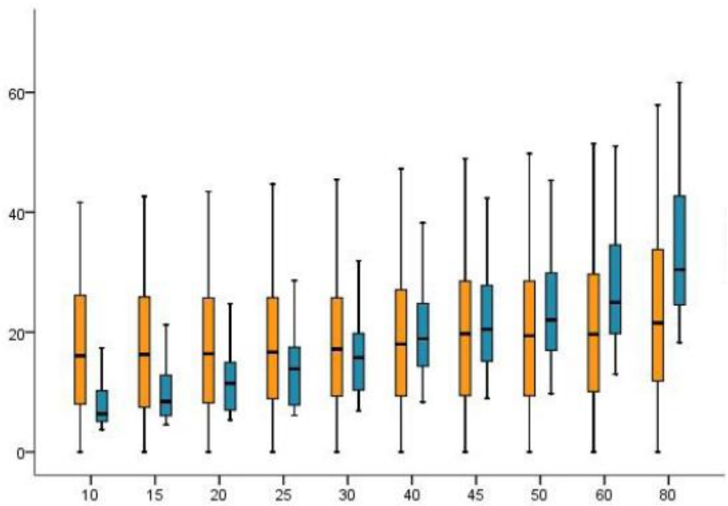

Fig. 5 Heating and cooling demand (KWhm2y) related to percentage of openings in both facades for Madrid

In the case of the embodied energy in materials, the opening percentage also plays a determinant role, since the amount of material used for both elements varies according to their impact on the facade. As seen in Table 1, the studied openings have more embodied energy than the walls, so in these cases, a greater number of openings means a higher energy consumption. If the window embodied energy per unit area of wall is greater than that of the openings, then the option to reduce this energy would be to increase the percentage of openings, and to compensate with the thermal performance for each climate zone.

In residential buildings, the proportion of openings and their arrangement in relation to the different volumes of the dwelling, have other functions related to the indoor environmental quality, such as ventilation or lighting, which also have to be considered in the design phase.

4. Discusion and conclusions

The initial investment in terms of materials are very big when compared to the energy demand by year, however, given that the lifespan of these actions is extended in time, it is particularly interesting to consider the impact of annual energy for which is necessary to establish a service life span. The energy consumption in terms of investment, is therefore closely linked to the approach of actions to maintain their long-term effectiveness.

The rehabilitation of existing buildings provides a unique opportunity for the utilization of resources. As seen, the production of new exterior enclosures implies an important environmental impact that can be minimized by exploiting and improving the existing enclosures. It is therefore necessary to establish the building stock as a resource for reducing the environmental impact of the construction sector.

The impact of embodied energy in materials can be reduced through the improvement in the production processes of construction elements and the use by designers of products with low environmental impact.

Currently the impact of embodied energy in materials is set to a secondary position compared to the energy required for the use of the building. However, as the construction solutions are improved and enclosures offer a better performance, it is gaining a greater presence. Given that we have considered the same energy incorporated in materials for all climatic zones, in those with more moderate climatic conditions, the impact of the materials becomes also higher.

The use of "free" strategies in terms of energy, allows us to start from an improved basis for the elimination of the environmental impact of the building. For example, a single module will require very different amounts of energy for air conditioning depending on the different orientations. If we establish the appropriate base conditions for the project, it will be possible to use simpler constructive solutions. Because of the wide range of scenarios faced by the construction industry, and in particular the rehabilitation sector, simple solutions geared to different design determinants must be found.

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